Hybrid query plan generation

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Abstract. A hybrid query is a requirement of data produced by data services and a set of QoS preferences w.r.t. the query execution. In this paper we present the problem of the hybrid query optimization and, in particular, the generation of the search space of hybrid query plans. We show how the constraints that characterize the generation of hybrid query plans are modeled and validated by implementing them in an action language. We present graphs with the experiment results that show the complexity of this generation.

Keywords: Hybrid queries, answer set planning, multi-objective optimization, logic programming, non-monotonic reasoning

1 Introduction

A hybrid query [CV11] is a spatio-temporal query over continuous and on-demand data provided by data services and accessible through interfaces (API). In particular, we focus on the characteristics associated to the on-demand data. Data consumers express their data needs along their QoS preferences. For instance, consider the data need "*Where are my friends at this moment?*" with the QoS preferences "*Privilege the execution price over the execution time and this in turn on the battery consumption*".

Hybrid queries are evaluated with a service coordination approach [CVVC12] that is represented by a query workflow. A query workflow [4] is a plan that coordinates a set of services with computing capabilities for processing the query. Services have QoS measures associated to their invocation and thus the execution of a query workflow has a cost that is the aggregation of the QoS measures. In centralized data bases the cost of query evaluation is the time, in distributed and parallel data bases the cost is two-folded in execution time and communication cost. The evaluation of hybrid queries in turn has a three dimensional cost: execution time, execution price, and battery consumption.

A finite set of query workflows implements the same hybrid query but there is a subset that satisfies the cost requirements of the user. For example, the

[4] We refer to *query workflow* and *query plan* indistinctly.

cheaper or the faster. This is a combinatory optimization problem of minimizing the cost of a query workflow QW that is a subset of activities A that implement data operations.

$$\min_{QW \subseteq A} \{cost(QW) : QW \text{is a query workflow}\} \quad (1)$$

The optimization of queries over data services must tackle challenges such as autonomy, non-durability of data, absence of fine grain data statistics, etc. In [OB04] the authors discuss some non-centralized query optimization approaches such as data mediation systems [TRV95,HKWY97] where the cost model only considers the execution time. The evaluation of queries over web services presented in [SMWM06] proposes a service coordination approach. A service coordination is optimized by ordering the service calls in a pipelined fashion and by tunning the size of data. Nonetheless, the control over data size (*i.e.,* data chunks) and selectivity statistics is a strong assumption because of the autonomy of services and the absence of data statistics in a real scenario. Another aspect to consider during the optimization is the selection of the service instances, which represents a factor for the service coordination cost. In [CAH05,WCSO08] the optimal selection of services with a multidimensional cost is proposed for optimizing the complete service coordination. This selection is done by solving a multiobjective assignation problem for a set of abstract services. However, the possibility to modify the order of service invocations is not considered and this is a key issue in the hybrid query optimization.

In this paper we focus on the generation of a search space of query workflows in order to get a finite set of hybrid query implementations. This work is the foundation for adding a cost model in the future and be ables to choose the most suitable query workflow w.r.t. user's preferences. This is important because a search space without constraints is in the order of $n!$ permutations in the number of activities required for evaluating the query. We propose a set of constraints modeled in an action language (*e.g.,* DLV-K) in order to characterize the construction of query workflows with sequential and parallel compositions, and to get only the coherent ones and therefore to reduce the size of the search space.

The paper is organized as follows. Section 2 gives the bases of the environments where hybrid queries take place and explains how the hybrid query plans are modeled with the notion of query workflow. In Section 3 we describe a set of constraints for modeling the query workflow generation using an action language. In Section 4 we show experiment results that confirm the complexity of the problem. Finally, we conclude this paper and present the future work in Section 5.

2 Querying dynamic environments

A dynamic environments is a set of distributed services that provide on-demand data, continuous data and computation functionalities. Queries over dynamic environments, so called **Hybrid queries**, are expressions of data requirements over

on-demand and continuous data provided by data services and whose execution is constrained by user's preferences (*e.g.,* price, battery consumption, execution time). For example, the spatio-temporal query presented in the previous section "*Where are my friends at this moment?*". In this paper we are interested in the hybrid queries over on-demand data. For example, "*What are the interests of my friend Joe*", where only on-demand data are considered.

In [CVVC12] the evaluation of hybrid queries with a service coordination approach is proposed. This approach assumes the existence of computation services with data processing capabilities instead of an off-the-shelf query engine. Service coordination models a plan for evaluating the hybrid query and is represented by a query workflow.

2.1 Data and computing services

A service is a software entity with an abstract functionality described by an Application Program Interface (API) with the specification of methods for accessing data. An operation has a name and a set of typified bound/free parameters [RSU95]. Each parameter has a role identified by a unique name in the method.

For simplicity, we illustrate APIs with the following form

`service_name:method_name(T:`B_1`?,...,T:`B_n`?, T:`F_1`!,...,T:`F_m`!)`

where the service identified by `service_name` has a method named `method_name` with `n` bound parameters and `m` free parameters. Bound and free parameters will be identified by question and exclamation marks respectively. Each parameter is typified by a data type[5] `T` and has a unique name within in the method header.

From this general notion of service, we distinguish two service specializations. (1) On-demand data service provides data in a request-response fashion through synchronous data operations. (2) Computing service provides a set of methods to perform operations over data (*e.g.*, distance estimation, ordering, correlation).

2.2 Query workflow

A query workflow represents a control flow among a set of activities. Each activity is a program that calls a data service method or a computing service method. The control flow is defined by workflow operators such as *sequence* or *parallel*.

A query workflow QW is modeled as a direct acyclic graph QW=*(V, E, init, finish)* where:

$$
\begin{aligned}
V &\text{ is a set of vertices}\\
E \subseteq V \times V &\text{ is a set of edges}\\
A \subseteq V &\text{ is a set of activities named by unique names}\\
init, finish \in A &\text{ are the initial } init \text{ and finish } finish \text{ activities of the } QW\\
O \subseteq V &\text{ is a set of workflow operators of the type } op = \{seq,\ par\}\\
&\text{tagged by unique labels.}
\end{aligned}
$$

[5] Data types are defined in the tuple data model in the thesis [CV11].

There are three activity specializations: the *activity* performs a service method invocation and always has a previous and a next activity, the *init* activity has no previous activity and its only goal is to launch the first *activity* of query workflow, the *finish* activity has no next activity and its only goal is to stop the query workflow execution after the last *activity*.

The compositions of activities $E \subseteq V \times V$ are defined by two workflow operators: sequential and parallel ones. A sequential composition *seq* represents the total order of a pair of activities a_1, a_2 such that $e_1 = (a_1, a_2)$. It means that the second activity a_2 must be executed after a_1. A parallel composition *par* represents the partial order of activities a_1, a_2, a_3, a_4 such that $e_1 = (a_1, a_2)$, $e_2 = (a_1, a_3)$, $e_3 = (a_2, a_4)$, $e_3 = (a_3, a_4)$. It means that a_2 and a_3 are independent from each other and are executed in parallel after a_1 and before a_4.

In the next section we present how we model the query workflow generation by abstracting the semantics of activities [CV11]. This semantics is inherited from the data operations implemented by the services.

3 Query workflow generation

Query workflow generation is the process of enumerating all the query workflows in order to have a search space for choosing a subset that satisfies the user's preferences. The enumeration without constraints is in the order of $n!$ and, in fact, the most of these query workflows would not be coherent w.r.t. the hybrid query.

The generation is done by constructing query workflows whose activities are subject to query workflow constraints. We model these constraints as action rules in the language DLV-K[6] that allows the sequential or parallel execution of query workflow activities.

In DLV-K, planning problems have a set of facts that represents the problem domain named background knowledge. The facts are predicates of static knowledge and are the input of the planning problem. Planning problems are modeled as state machines described by a set of fluents and a set of actions. A fluent is a property of an object in the world and is part of the states of the world [Bar03]. Fluents may be true, false or unknown. An action is executable if a precondition holds in the current state. Once an action is executed, the fluents and thus the state of the plan are modified. The action rules define the subset of fluents that must be held before the execution of action (*i.e.,* preconditions) and the subset of fluents to be hold after the execution (*i.e.,* postconditions). Finally, a goal is a set of fluents that must be reached at the end of plan. A goal is expressed by the conjunction of fluents and by a plan length $l \in \mathbb{Z}_+$.

The mapping from query workflows generation to a planning problem is direct, as shown in Table 1. The APIs and the hybrid query are modeled as facts of the background knowledge. The execution state of a query workflow is modeled as fluents and query workflow activities as actions.

[6] http://www.dbai.tuwien.ac.at/proj/dlv/k

Query workflow	Planning problem
APIs, hybrid query	Facts (background knowledge)
Query workflow states	Fluents
Query workflow activities	Actions
Result delivery	Goal: `finished?(`$l \in \mathbb{Z}_+$`)`

Table 1. Mapping from Query workflow to a Planning problem

In the following, we show, along with a simple example, how we represent the background knowledge for query plan generation. Afterwards, we show how the query workflow state and activities are expressed in DLV-K.

3.1 Background knowledge

The background knowledge is the input for query workflow generation and it is represented by a set of facts. The facts are two-folded in (1)service interface representation and (2)hybrid query representation.

Service interface Consider the following three methods of service interfaces:

- `profile:profile(string:nickname?,int:age!,string:sex!,string:email!)` This method provides the user profile formed by `age, sex` and `email` of a given user with a `nickname`.
- `interests:interests(string:nickname?,string:tag!,real:score!)` This method provides the interests of a given user identified by a `nickname`. An interest is represented by a `tag` and has a `score` that qualifies the interest over the tag.

The service interface and its methods are described by the facts `service_interface/1` and the `operation/2` respectively. We distinguish between bound and free parameters with the facts `bound_p/4` and `free_p/4`. The normal form of a parameter is stated by `parameter/4` and this rule guarantees that the parameter name is unique in the context of the service method.

```
service_intereface(profile).                                    1
operation(profile,      profile).                               2
bound_p(profile, profile, nickname, string).                    3
free_p(   profile, profile, age,      int).                     4
free_p(   profile, profile, sex,      string).                  5
free_p(   profile, profile, email,    string).                  6
                                                                7
service_interface(interests).                                   8
operation(interests,   interests).                              9
bound_p(interests, interests, nickname, string).                10
free_p(   interests, interests, tag,      string).              11
free_p(   interests, interests, score,    real).                12
                                                                13
parameter(DSN,ON,PN,T):- bound_p(DSN,ON,PN,T).                  14
parameter(DSN,ON,PN,T):- free_p(DSN,ON,PN,T).                   15
```

Listing 1.1. Service interfaces

Hybrid query Now consider the query "*What are the interests of my friend Joe*" that is represented by the hybrid query in facts:

```
project_(p,nickname,n).                                    1
project_(i,score,s).                                       2
project_(i,tag,t).                                         3
retrieve_(profile,profile,p).                              4
retrieve_(interests,interests,i).                          5
select_(p, nickname).                                      6
join_(p,nickname,i,nickname).                              7
```

Listing 1.2. Hybrid query in facts

This query expresses the need of data over the methods `profile:profile` and `interests:interests` methods, the nickname of the profile is filtered and correlated with the nickname of interests. Finally, the parameters nickname, score and tag are projected.
Observe that the selection over the nickname attribute is indicated only in intention because the equality operators are not significant for the query workflow generation.

3.2 Query workflow activities

The query workflow activities are represented as actions in DLV-K. Below we present the intuition of activities, for more details about the semantics of activities please refer to [CV11]. In general, the activities are predicates that hold if their facts from background knowledge are true. There are also activities that are independent from facts.

init and finish These activities have the special purpose to `init` and `finish` the query workflow execution accordingly with our model in subsection 2.2. Thus the semantics is not associated with the query processing and there is no dependency with the background knowledge.

on-demand This activity establishes a connection with a data service method and requires a method of a service and the expressed need of the user to be queried.

```
on_demand(DS) requires operation(DSN,ON), retrieve_(DSN,ON,DS).   1
```

Listing 1.3. on-demand activity

bind_selection This activity invokes and retrieves data from a service method. The invocation is done by a given bound parameter valid in the service interface definition. The hybrid query must express that data are required from this service method respect to a selected bound parameter.

```
bind_selection(DS,BP) requires operation(DSN,ON),                 1
        retrieve_(DSN,ON,DS), bound_p(DSN,ON,BP,_), select_(DS,BP). 2
```

Listing 1.4. bind-selection activity

bind_join The required correlation in the hybrid query is performed by this activity. Correlation is binary between data from two service methods on a parameter from each one. The parameter from the outer method must be

bound. This activity is analogous to `bind_selection` but `bind_join` takes the value of a bound parameter from the output of another method (*i.e.,* the inner method).

```
bind_join(DS1,P1,DS2,BP2)                                    1
   requires operation(DSN1,ON1), retrieve_(DSN1,ON1,DS1),    2
            parameter(DSN1,ON1,P1,_),                        3
            operation(DSN2,ON2), retrieve_(DSN2,ON2,DS2),    4
            bound_p(DSN2,ON2,BP2,_),                         5
            join_(DS1,P1,DS2,BP2).                           6
```

Listing 1.5. bind-join activity

select The select activity performs the filtering over a valid parameter of a required service method in the hybrid query.

```
select(DS,P) requires operation(DSN,ON),                     1
                      retrieve_(DSN,ON,DS),                  2
                      parameter(DSN,ON,P,_),                 3
                      select_(DS,P).                         4
```

Listing 1.6. select activity

project This activity projects a parameter of a service method required in the hybrid query.

```
project(DS,P) requires project_(DS,P,_).                     1
```

Listing 1.7. project activity

The semantics of activities described above is completed with constraints that define their preconditions and postconditions.

3.3 Query workflow constraints

The query workflow constraints define the conditions associated to the execution of activities. A condition is a state of knowledge modifiable by the execution of the activities. Conditions also define when the activities can be executed. Hence, we talk about preconditions and postconditions of activities. A state is composed by a set of fluents that occur during the execution of activities. The rules that define when a fluent occurs can be static or dynamic. Static rules are those that occur given the truth-value of a subset of fluents, and dynamic rules occur given the truth-value of a subset of fluents and after the execution of an activity.

Below we present the constraints that describe how the activities can be performed and how a query plan should be constructed.

- **init and finish** The first executable action in a query workflow is **init**. This activity has no previous activity, thus its precondition is that the query workflow is not `initiated` and produces a new state with `initiated`. The last activity is `finish` and there is no other activity executed after this one. The precondition to execute `finish` is that there is not evidence that the query workflow is `finished` and the data is already `delivered` (See `output` constraint below for details about `delivered`). The postcondition of `finish` is `finished` and this is always the goal for the generation.

```
executable init if   -initiated.                                    1
caused     initiated after init.                                    2
executable finish if not finished, delivered.                       3
caused     finished after finish.                                   4
```

Listing 1.8. `init` and `finish` activities

– **on-demand** Once initiated the plan, the data services must be `connected(DS)`. This fluent is produced by the execution of `on_demand(DS)` activity.

```
executable on_demand(DS) if initiated.                              1
caused     connected(DS) after on_demand(DS).                       2
```

Listing 1.9. on-demand activity

During the execution, all data services must be connected. Therefore, there is a fluent `all_connected` that is false if there is not evidence that a data service is connected. Otherwise, it is true.

```
caused -all_connected if not connected(DS).                         1
caused  all_connected if not -all_connected.                        2
```

Listing 1.10. all_connected fluent

– **bind_selection** One of the activities that implements data retrieval is bind selection. It is only executable if there is not evidence that the data service `DS` has already been retrieved and if there is a connection with `DS`. Once the bind selection is executed, the fluent `retrieved(DS)` is true. `retrieved(DS)` is an inertial fluent, thus the re-execution is not possible.

```
executable bind_selection(DS,BP)                                    1
       if not retrieved(DS), connected(DS).                         2
caused retrieved(DS) after bind_selection(DS,BP).                   3
```

Listing 1.11. bind_selection activity

– **selection** The filtering of data is done by the `selection` activity. It is executable if there is not evidence that the parameter `P` of `DS` has already been selected. There is also need that the data from `DS` has been retrieved and obviously the selection `select_(DS,P)` must be part of the hybrid query. The execution of the selection makes the fluent true `selected(DS,P)` and it is inertial, so the re-execution of the selection `select(DS,P)` is not possible.

```
executable select(DS,P) if not selected(DS,P),                      1
                                retrieved(DS), select_(DS,P).       2
caused     selected(DS,P) after select(DS,P).                       3
```

Listing 1.12. select activity

In order to be aware of the state of selection over all the required parameters of a method `DS`, the all_selected_from(DSOName) becomes true if there is no other parameter pending to be selected.

```
caused -all_selected_from(DS) if not selected(DS,P), select_(DS,P).  1
caused  all_selected_from(DS) if not -all_selected_from(DS),         2
    retrieved(DS).
```

Listing 1.13. all_select_from fluent

Analogously, all parameters from all data services must be selected when they are required. Therefore, there is the fluent `all_selected`. This fluent is true if there is no other method `DS` pending to be selected.

```
caused -all_selected if -all_selected_from(DS), select_(DS,P).          1
caused -all_selected if -all_selected_from(DS), not select_(DS,P),      2
    parameter(DSN,ON,P,_), retrieve_(DSN,ON,DS).
caused  all_selected if not -all_selected.                              3
```

Listing 1.14. all_select fluent

– **projection** This activity is executable if there is not evidence that the parameter `P` of `DSOName` has been projected. There is also need that the data from `DSOName` be retrieved. The execution of projection makes the fluent `projected(DSOName,P)` true and it is inertial, thus the re-execution of the projection is not possible.

```
executable project(DS,P) if not projected(DS,P), retrieved(DS),         1
    project_(DS,P,_).
caused     projected(DS,P) after project(DS,P).                         2
```

Listing 1.15. project activity

The projected fluent is true once the action `project(DS,P)` is done. During the query workflow execution, all the required parameters must be projected. For `DS` grain the fluent `all_projected_from(DS)` is true if there is no other parameter from `DS` pending to be projected. For the entire query, the fluent `all_projected` is true if there is no other `DS` pending to be projected.

```
caused -all_projected_from(DS) if not projected(DS,P), project_(DS,P, 1
    _).
caused  all_projected_from(DS) if not -all_projected_from(DS) after   2
    project(DS,P).
                                                                        3
caused -all_projected if -all_projected_from(DS), project_(DS,P,_).     4
caused  all_projected if not -all_projected.                            5
```

Listing 1.16. all_projected_from fluent

– **output** Once the hybrid query is processed, data must be delivered by the activity `output`. In order to model this precondition, the fluent `query_processed` is true if all the other possible activities have been processed. Otherwise, the fluent is `-query_processed`.

```
caused -query_processed if not all_connected.                           1
caused -query_processed if not all_retrieved.                           2
caused -query_processed if not all_selected.                            3
caused -query_processed if not all_projected.                           4
caused  query_processed if not -query_processed.                        5
```

Listing 1.17. query_processed fluent

Once the query is processed, the `output` activity delivers the result and the fluent `delivered` becomes true.

```
executable output if query_processed, not delivered.                   1
caused    delivered after output.                                       2
```

Listing 1.18. output fluent

4 Experiments

We performed experiments with a set of hybrid queries described below. The objective of the experiments is to measure the size of the search space of query

workflows given a fixed number of activities and a goal to define the length of the query workflow.

4.1 Configuration

In order to test the performance of query workflow generation, we have defined four hybrid queries. All are based on the query example of subsection 3.1. In order to make more complex the generation of query plans, we add two data operations. The resulting queries are configured as follows:

	Data operator			
Query	select_(p,age)	join_(p,nickname,i.nickname)	Description	# activities
[Q1]	✗	✗	no additional operators	11
[Q2]	✓	✗	+unary data operator	12
[Q3]	✗	✓	+binary operator	13
[Q4]	✓	✓	+both unary and binary operator	14

Table 2. Query configuration

Another dimension for the test is the max length of plans. The generated plans depend on a required plan length. In DLV-K, one must specifies the desired length that determines the size of the search space of query workflows and thus the required time for the generation.

In the tests we used lengths from 6 to 14, and we will measure (1)the length of the generated plans, (2)the size of the search space, and (3) the execution time of the generation.

4.2 Results

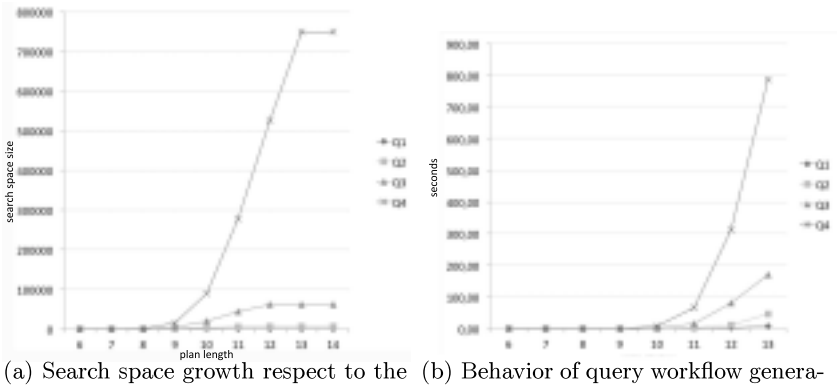
The data retrieved from the experiments show (1) the behavior of the search space growth during the generation and (2) the time required for generating all the search space.

Each hybrid query requires a fixed number of activities accordingly with the number of data operators required to process the query result. Given that the length l bounds the size of query plans, there are hybrid queries that require a largest l than others. For example, $Q1$ with 11 activities, requires at least an $l = 7$ to get query workflows with the must possible parallel compositions, and at most $l = 11$ to get completely sequential compositions. For reasons of space we invite the reader to visit the URLs http://goo.gl/XKZuL and http://goo.gl/z4iu3 to appreciate examples of query workflows of 7-length and 11-length respectively. The growth of search space is shown in Table 3 and, as was expected, the size of search space tends to be stable once the maximum length is reached. For example, $Q1$ reach the maximum length with $l = 11$. This is analogous for $Q2$, $Q3$, and $Q4$. Nevertheless the size of search space for each one is considerably

l	Queries			
	Q1	**Q2**	**Q3**	**Q4**
6	0	0	0	0
7	4	4	20	20
8	62	128	598	1192
9	278	956	5062	15820
10	578	3068	19822	90100
11	718	5368	43698	277800
12	718	6268	62358	525476
13	718	6268	62358	749840
14	718	6268	62358	749840

Table 3. Search space growth respect to the plan length

bigger than the others less complex. In the Figure 1(a), you can see that the search spaces have an exponential growth until the max length.



(a) Search space growth respect to the plan length

(b) Behavior of query workflow generation during the time

Besides the size of search space, the time for processing the query workflow generation is also exponential (See 1(b)) and it is not feasible to generate completely the search space in the context of query optimization. Thus, this enumeration must be done implicitly in order to avoid the combinatorial explosion.

5 Conclusion and future work

In this paper we presented the constraints for generating query workflows that model the plans of hybrid queries. The constraints represent the semantics of

query workflow activities that is analogous to the data operation implemented by the associated service method. We used the action language DLV-K for modeling the planing problem of query workflow generation in order to get a first (and naive) search space generation towards the optimization of hybrid queries. The results show that time complexity for query workflow generation is exponential.

The constraints must be extended in order to consider the continuous data operators for completely modeling hybrid queries. These constraints can be taken to model a more sophisticated query workflow generation. This implies the abstraction of data operators types and their associated constraints in a general form.

Theoretically, query workflow generation can be modeled mathematically by taking the constraints presented here and modeling an objective function. Additionally, the equivalence and coherence of query workflows must be proved.

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